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Continuous recording of pulmonary artery pressure in unrestricted subjects

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SUMMARY Continuous ambulatory pulmonary artery pressures were recorded using a conventional No 5 French Goodale-Lubin fluid filled catheter linked to the Oxford Medilog system of a portable transducer-perfusion unit and miniaturised recorder. Data retrieval and analysis were performed using a PB2 Medilog playback unit linked to a PDP 11 computer system. The total system has a frequency response linear to 8 Hz allowing accurate pressure recording over the full range of heart rates. Ten recordings in 10 patients yielded artefact free data for 80% or more of the recorded period. This inexpensive reliable method allows pulmonary artery pressures to be recorded in unrestricted subjects.

The diagnosis of pulmonary hypertension, primary or secondary, requires the accurate measurement of pulmonary artery pressure. Despite occasional reports of non-invasive methods[1] reliable assessment of pulmonary pressure still requires cardiac catheterisation.

Initially, right heart catheterisation was confined to the diagnostic laboratory, where recordings are generally limited to a period of minutes only.[2] Catheter modifications by Bradley,[3] Fife and Lee,[4] and Swan *et al*[5] made it possible for pulmonary artery pressure recordings to be performed safely at the bedside over moderately long periods of time. Nevertheless, the recording equipment is bulky, and this, together with the unknown hazards of ambulatory pulmonary catheterisation, have restricted the use of this technique to severely ill patients confined to bed.[6 7] Hence variations in pulmonary artery pressures due to normal physiological influences are largely unknown. This is true both in health and in disease. The response of primary pulmonary hypertension to various vasodilator agents has been of particular interest recently.[8–10] Nevertheless, the absence of reliable information on the range of spontaneous variability in this and other forms of pulmonary hypertension seriously limits the evaluation of therapeutic interventions.[11] A method for prolonged recording of pulmonary artery pressure in unrestricted subjects is thus required.

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The only report of continuous ambulatory pulmonary pressure monitoring is by Nathan *et al*.[12] These workers used a specially developed solid state catheter and recording system. We report our experience using a conventional fluid filled catheter and a standard recording system for measuring pulmonary artery pressure in unrestricted subjects.

Patients and methods

Ten patients (nine men and one woman) undergoing diagnostic cardiac catheterisation, including right heart studies, gave consent to additional ambulatory recordings of pulmonary artery pressure. The study protocol was approved by the hospital ethical committee. The Table shows the clinical details together with maximum and minimum recorded pulmonary systolic and diastolic pressures.

EQUIPMENT

Catheter

Pulmonary arterial catheterisation was performed via a right antecubital percutaneous entry in five patients and via a right subclavian venous entry in five under local anaesthesia with plain 1% xylocaine. A No 5 French Goodale-Lubin catheter was inserted and its tip positioned in the main pulmonary artery under fluoroscopic guidance. When venous access at the antecubital or subclavian site had been achieved a bolus of 4000 units of heparin was given through the catheter. Its position was checked for stability during coughing and deep breathing. The catheter was firmly fixed at its entry site with a suture and an adhesive skin dressing.

Table *Pulmonary arterial pressures (mm Hg)*

Case No	*Age (y)*	*Diagnosis*	*NYHA functional class*	*Pulmonary artery pressure*				*Duration of recording (h)*
				Systolic		*Diastolic*		
				Max	*Min*	*Max*	*Min*	
1	49	CAD	III	62	27	28	8	24
2	70	MI	III	50	20	20	5	20
3	57	CAD	II	28	15	7	1	21
4	61	AI	II	36	22	21	4	22
5	55	CAD	III	37	16	17	2	10
6	62	CAD	II	35	10	17	3	10
7	48	MS	II	88	32	55	20	25
8	70	MI	III	75	50	38	17	10
9	53	AS	II	45	17	25	4	11
10	71	AI	III	92	53	60	32	10

CAD, coronary artery disease; MI, mitral incompetence; AI, aortic incompetence; MS, mitral stenosis; AS, aortic stenosis; max, maximum; min, minimum.

Initial experiments using single end hole catheters such as a No 5 French Cournand or Swan-Ganz catheter gave consistently poor recordings because of repeated impaction of the single catheter orifice against the vessel wall. A No 6 French NIH catheter with six side holes was then used to ensure a free passage between the lumens of the pulmonary artery and catheter for the transmission of a pressure pulse; however, clotting of the small side holes occurred in four of 12 preliminary cases studied using this catheter. All 10 cases reported below were studied using a No 5 French Goodale-Lubin catheter with two side holes

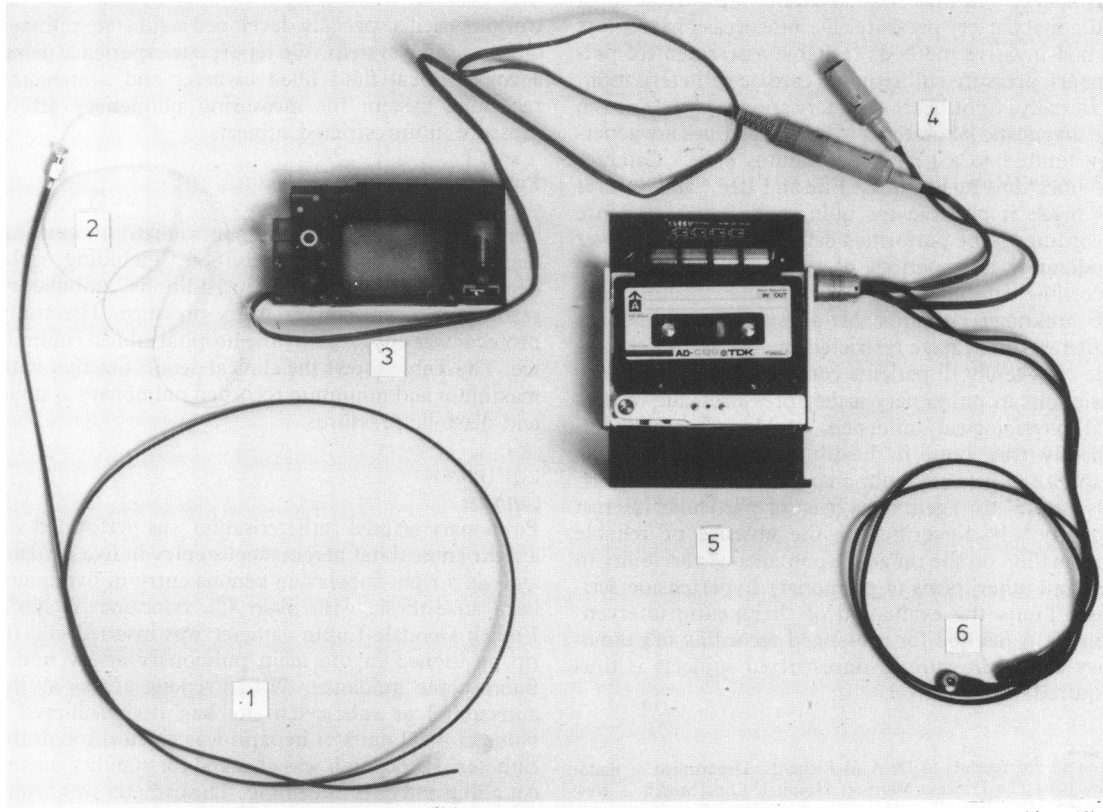

Fig. 1 *Pulmonary artery pressure recording system using (1) a No 5 French Goodale-Lubin catheter, (2) connection tubing, (3) a transducer-perfusion unit, (4) a connection plug, (5) a Medilog miniaturised tape recorder, and (6) ECG leads.*

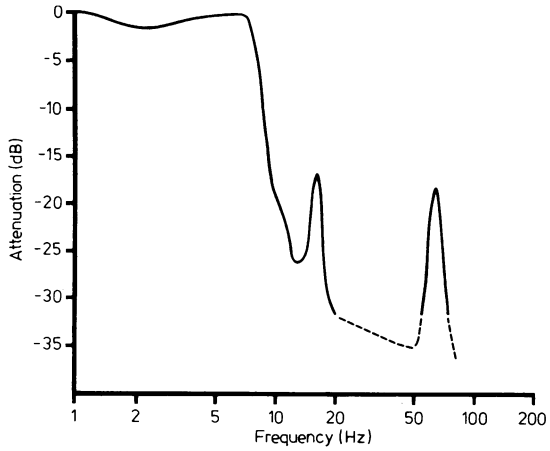

Fig. 2 *Frequency response of the pulmonary artery pressure recording and playback system.*

and an end hole.

Transducer-perfusion unit and recorder

The catheter was connected to the transducer-perfusion unit with 80 cm of non-distensible tubing (internal diameter 0·6 mm). The 100 g unit consists of a semiconductor strain gauge and a delta pump cast together in an epoxy casting, which also contains a 40 ml capacity reservoir for heparinised saline. The fluid channel interconnections are integrally moulded in the casting and include a three way tap for calibrating the transducer while in use or for flushing the catheter when necessary. Anticoagulation was provided by a solution of 8000 IU of heparin in 40 ml of 0·9% saline for irrigating the catheter at a rate of 3–4 ml/h. This equipment is of proven reliability and its use in continuous systemic arterial pressure recording is reported elsewhere.[13 14] To maintain the patency of the catheter the unit pump speed was reset to give the rate of irrigation mentioned above. This was approximately double the rate used with systemic arterial irrigation. The transducer was carried at chest height with the semiconductor strain gauge positioned under fluoroscopic guidance over the tip of the catheter in the pulmonary artery. The transducer signal was recorded together with the electrocardiogram from chest leads on a multichannel miniaturised Medilog tape recorder worn on a belt at waist level. The total weight of the equipment was 900 g. Fig. 1 shows components of the system. At least two calibrations using a mercury column were made during each study usually near the beginning and end of the recording.

A simple protocol, which included periods of lying supine and standing and mild symptom limited exercise climbing several flights of stairs, was completed by each patient.

Data retrieval and analysis

Data retrieval and analyses were performed by a PB2 Medilog playback deck coupled with a PDP11 computer system which provided graphical and digital printouts of systolic, diastolic, and mean pulmonary artery pressures and heart rate, all averaged over 10 beat samples. The facility for beat by beat analysis is available. The time required from the start of tape playback to printout of data was about 30 minutes.

Results

Patient tolerance of the ambulatory recording procedure was excellent. All patients were able to sleep satisfactorily with the equipment in place. Recordings ranged in duration from 10 to 25 hours. No complications occurred either in this group of 10 patients or in any of the 20 patients in whom preliminary studies had been performed using other catheters.

On playback, mercury column calibrations matched perfectly on all tapes indicating negligible baseline drift. The frequency response of the whole system—that is, from catheter tip to the output of the Medilog playback amplifier—was laboratory tested in a similar way to that described by Goldberg *et al.*[15] Fig. 2 shows the system response. Two resonances occurred, one at 16 Hz and one at 60 Hz, which can be attributed to the narrow extension tubing and the NIH catheter respectively.

The Medilog playback amplifier and the Medilog recorder amplifier both showed a frequency response dropoff at 8 Hz, which limits the capability of the whole system to record high frequency waveforms. The fifth harmonic of a pressure waveform associated with a heart rate of 100 beats/min can still be recorded under such circumstances.

The fluid filled catheter system was compared in situ with a high fidelity transducer tipped Millar catheter during catheterisation. Fig. 3 shows recorded waveforms. The fluid filled catheter response was not damped thus allowing direct comparison with recordings from the Millar catheter. From Fig. 3 it is clear that the pressure waveforms matched each other. With the filtering given by the recording and playback amplifiers, the fluid filled catheter system gave a "clean" waveform (Fig. 4).

The transducer was placed on the anterior chest wall approximately 5 cm away from the tip of the catheter. This caused a change in the zero reference pressure of about 4 mm Hg if the patient changed from lying to standing.

All 10 studies yielded artefact free data for 80% or more of the recording time. Substandard recordings were due to repeated clotting of the catheter tip and damping of the pressure wave because of kinking of the catheter or extension tubing or both. Clear trac-

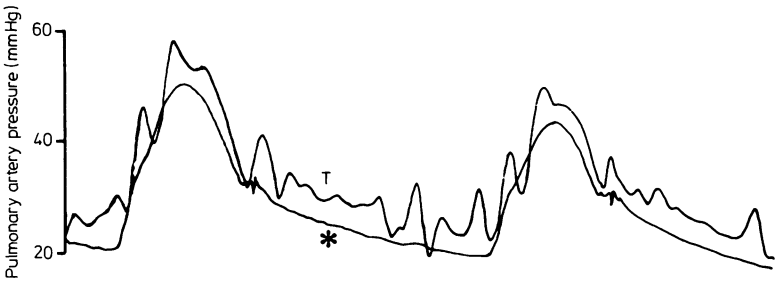

Fig. 3 *Comparison of pulmonary artery pressure waveforms obtained with an undamped fluid filled catheter (T) and a Millar* catheter.*

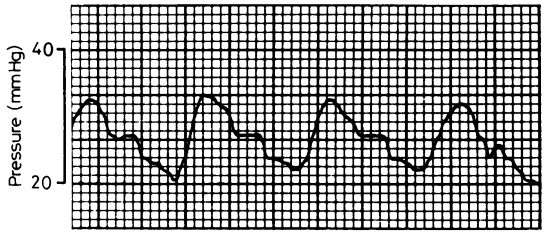

Fig. 4 *Pulmonary artery pressure waveform output from the playback system.*

ings of pulmonary artery pressure during exercise were obtained. In four patients symptoms occurred during exercise including dyspnoea, chest tightness, and threatened syncope. In each case symptoms coincided with the peak pulmonary artery pressure. Systolic pressures recorded ranged from 10 to 92 mm Hg and diastolic pressures from 1 to 60 mm Hg. Two cases are reported in more detail to illustrate the type of information made accessible by the technique.

CASE REPORTS

Case 7—A 48 year old woman with known mitral stenosis presented with a six month history of progressive shortness of breath on exertion. At right heart catheterisation a pulmonary artery pressure of 50/25 mm Hg was recorded. Over a 24 hour period, however, ambulatory recording showed pressures as low as 32/20 mm Hg at rest. With exercise, she became symptomatic with mild dyspnoea and chest tightness coinciding with a maximum recorded pressure of 88/55 mm Hg (Fig. 5).

Case 9 presented to his general practitioner with syncope and chest pain. Clinical signs suggested aortic stenosis. Cardiac catheterisation showed normal coronary arteries and a normal resting pulmonary artery pressure (17/4 mm Hg). A resting peak aortic systolic gradient of 80 mm Hg confirmed severe aortic valve stenosis. The ambulatory study recorded a peak pulmonary artery pressure of 45/25 mm Hg coinciding with dyspnoea and "lightheadedness" after the patient had briskly climbed three flights of stairs.

Both patients were asymptomatic at rest and at low levels of exercise. The studies allowed pulmonary

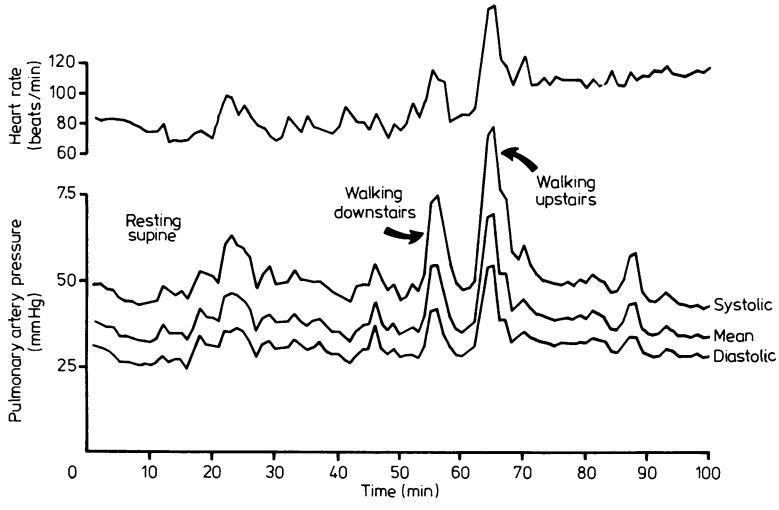

Fig. 5 *Pulmonary artery pressure and heart rate at rest and during mild exercise (case 7).*

artery pressures to be matched with symptoms during daily activities.

Discussion

The technique used in this study shows the feasibility of continuous recording of pulmonary artery pressure in unrestricted subjects. The equipment is readily available and has been widely used in ambulatory studies of systemic arterial pressure. We used the standard readily available Medilog miniaturised tape recorder with a four channel facility for multiple recordings. Our method has a limited frequency response which is, however, adequate for pressure recording if not for waveform analysis. The problem of clotting of the catheter tip has been avoided by using multi-holed catheters, moderate doses of heparin, and an increased pump flow. Heparin bonded catheters, which are commercially available and have been successful in reducing pressure wave damping in Swan-Ganz catheters,[16] may be used as an alternative approach. The problem of zero referencing can be overcome by taking a lateral radiograph and estimating the catheter to transducer distance; this can then be used to correct the recorded value if an absolute pressure is needed. The data retrieval system allows beat by beat analysis of systolic, mean, and diastolic pressures and heart rate. Our use of a catheter with a lumen permits blood sampling for measuring oxygen content and thereby calculating cardiac output by the Fick method. Central injection of an indicator through the catheter allows cardiac output to be measured by the Hamilton-Stewart method. The catheter is also suitable for high pressure pulmonary contrast angiography.

The only alternative technique of ambulatory pulmonary artery pressure monitoring is that described by Nathan *et al*,[12] who used a solid state transducer tipped catheter. Their system had a high frequency response, and the positioning of the transducer in the pulmonary artery eliminated any problem with zero referencing. As yet, however, the components of this system are scarce, expensive, and fragile and do not allow in vivo calibration.

The system used is invasive and hence attended by potential hazards—for example sepsis or perforation of cardiac structures. The catheters used in our study were smaller than the Swan-Ganz catheters used for routine haemodynamic monitoring and less stiff than many pacing wires used in endocardial pacing. Most complications reported with long term pulmonary arterial catheterisation have been due to the impaction of an inflated balloon in a distal branch of the pulmonary artery with resulting perforation of the vessel.[17 18] The absence of a balloon on the catheter we used is an important safeguard, but great care is needed with skin fixation to ensure that the catheter does not pass further into the vein. Our experience and that of Nathan *et al*[12] suggests that ambulatory pulmonary arterial catheterisation for up to 24 hours is safe and well tolerated.

Ambulatory recording of pulmonary arterial pressure using fluid filled catheters and readily available components is versatile and practical and can be used in the investigation of many hitherto unresolved physiological, pathophysiological, and therapeutic problems affecting the pulmonary circulation. Preliminary studies indicate that by the addition of another transducer perfusion unit connected to a brachial artery cannula pulmonary artery and systemic artery pressures may be recorded simultaneously in unrestricted subjects.

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